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Making a Transmit Lowpass Filter

Tony Nailer G4CFY responds to a customer request by developing a lowpass filter suitable for transmit purposes.

One of the projects I have wanted to create for some time as companion to my 5-band receive bandpass filters is a 5-band transmit lowpass filter. Fortunately I had a request from a prospective customer for a 4-band transmit lowpass filter so I had motivation to bring it to fruition.

The last time this was done in *PW* was an article entitled *HF Bands Low-pass Filter* by **Stefan Niewiadomski** in February 2005. It used a 3-band board that could be daisy chained to another to produce a 6-band filter set. These two boards were housed in a stand-alone case with two switches, one for input and one for output.

It was quite practical but not very elegant and entailed 18 toroidal coils and wiring six input coaxial cables and six output coaxial cables. I still advertise a 6-band version of his board in the *PW* PCB Service.

Filter Choices

A lowpass filter is usually a Pi shape (like Stonehenge) with capacitor supports to ground and an inductor as the lintel. Alternatively is can be a T shape with two inductors in series between input and output and with a central capacitor support in the middle.

The most popular configuration is the Pi and the smoothest is the **Butterworth** that has a flat low frequency characteristic and then rolls off smoothly at the cut-off frequency before diving at a rate of 6dB for every doubling of frequency, for each Pi section. Although it has relatively poor attenuation, it does present a near constant load impedance across a wide frequency range.

An improvement over the Butterworth is the **Chebychev** type that uses different Pi sections in series to sharpen the slope of the roll-off and it was this type using a 3-section Chebychev network that Stefan used in his family of filters.

The penalty for a sharper roll-off and greater ultimate attenuation is more passband ripple and non-constant input impedance with frequency. This is not really an issue when used as a lowpass filter with a cut-off just above the operating frequency but there is no guarantee that the filter will present low impedance at some higher spurious or harmonic frequency where serious attenuation is needed.

A further development of the Pi network is to add a capacitor in parallel with each inductor in the network to produce parallel resonance at specific frequencies. This filter is called an Elliptic lowpass filter and each support and lintel are called branches, so a double Pi is called a 5-branch network.

In a 5-branch filter there will be two parallel resonances, one placed as close as 1.5 times the cut-off frequency and the other further on to prevent the stopband from rising unnecessarily.

This filter uses the first parallel resonance to create a notch frequency to make the roll-off steeper. The effect would be to have a return curve on the upper side of the notch, which would spoil its ultimate attenuation and that is the purpose of a subsequent notch to pull the curve back down again.

As a result of these notching techniques, the Elliptic filter has a much sharper roll-off than even the Chebychev filter and a better ultimate attenuation. The passband also, strangely, stays smooth like that of a Butterworth filter.

Tables for the various components for the 5-branch filter have been published in the *ARRL Handbook* since the mid-1990s. These have been selected from an almost infinite number of possible variants for those with standard values for the support capacitors, which have the largest values.

My 5-band Filter

No doubt you realise where this is leading and my filter uses a 5-branch Elliptic LPF with values derived from the *ARRL Handbook* table as set out in **Table 1**.

The bottom four filters were chosen as the closest at a tenth of the wanted frequency and the values from the tables were then simply divided by ten to give operation ten times higher.

C2 and C5 are the parallel resonating capacitors and all but three are non-standard values.

Table 1. Filter Components

Filter	Band(m)	C1(pF)	C2(pF)	C3(pF)	C4(pF)	C5(pF)	L1(μH)	L2(μH)
28	80	470	33+18	1000	150	390	2.16	1.84
1x10	40	270	33	560	47+47	220	1.21	1.0
13x10	20	120	8.2+4.7	270	18+18	100	0.59	0.51
14x10	15	120	10+3.3	220	22+15	100	0.45	0.38
22x10	10	68	5.6+2	150	22	56	0.33	0.28

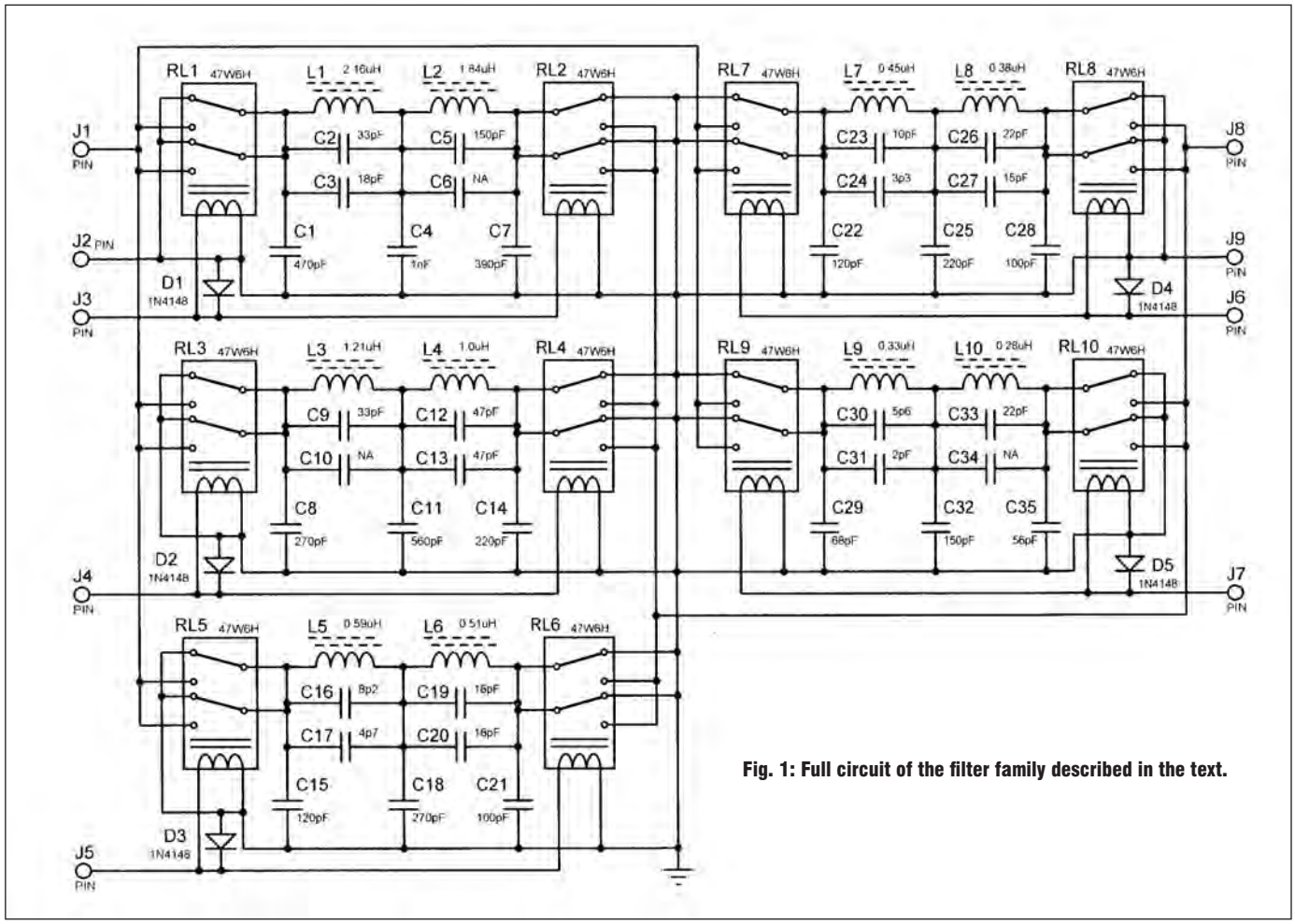

Fig. 1: Full circuit of the filter family described in the text.

My 5-band receive filters are switched using special diodes with low forward voltage drop and high RF isolation. This is possible for transmit and has often been used in private mobile radio (PMR) transceivers up to 25W and on both VHF and UHF.

My transmit filter, though, was originally intended to handle up to 50W so I decided to use high sensitivity versions of the 47W/6 Post Office approved relay. They are capable of carrying 2A across the contacts and by paralleling the switch sections, means a 4A continuous capability. So the power handling is $P = I^2 \times R$, $= 16 \times 50 = 800W$, which is way more than necessary. A pair of relays used for each filter draw a combined current of 30mA from a 13.5V line.

Making the Coils

When using toroids it's a good idea to use ones with sufficient inductance factor that the number of turns is not excessive. The T68-2 is good at low HF and has an inductance factor A_L of 3.6μH per 25 turns. This means that for 2.16μH and 1.84μH required for 80m they need fewer than 25 turns. The calculation is $N = 25 \times \sqrt{(A_L/\mu H)} = 25 \times \sqrt{(3.6/2.16)} = 19t$. For this number of turns 19SWG enamel wire is suitable.

A similar procedure was used for 40m where T68-6 cores were used with a factor of 2.9μH/25t, then for 20m, 15m, and 10m T50-6 cores with a factor of 2.5μH/t were used. See **Table 2**.

Printed Circuit Board

The full circuit of a family of filters is shown in **Fig. 1.** I laid out a PCB to accommodate relays each side of the filters with space for all coils to be T68 size and for a pair of parallel resonating capacitors across each coil. The toroids would be mounted with their axes at 90° to each other and the adjacent filters to have coils also at right angles to neighbouring filters.

Capacitors could be 50V or 100V working low-k NPO ceramic types if possible and polyester blocks for large values. Unfortunately, ceramic plate types are increasingly difficult to obtain and values over 100pF are now usually only available in multilayer ceramic COG types. Polystyrene types are fine at low HF but are too inductive at higher frequencies and are also as much as £2 each. Mica are fine at all frequencies but are also as much as £2 each.

So the board had to be laid out to accommodate disc ceramic, multilayer ceramic or polyester block, each with 5mm lead spacing. A board was produced and went well with good component density and no links or crossovers. An artwork was printed off and used during a PCB manufacturing run and the board was drilled, cropped and filed.

Table 2. Coil Details

Band	Coil L1	turns	cm	Coil L2	turns	cm	SWG	core
80	2.16	19	43	1.84	18	40	19	T68-2
40	1.21	16	34	1.0	14	32	19	T68-6
20	0.59	12	25	0.51	11	23	21	T50-6
15	0.45	10	20	0.38	9	19	21	T50-6
10	0.33	9	19	0.28	8	18	21	T50-6

Assembly and Test

I assembled the 80m filter first, complete with input and output relays, and tested it using a Marconi TF2370 110MHz spectrum analyser and tracking generator combination.

The filter had the cut-off in the right place but the notches for the parallel resonances were not deep. The ultimate stopband was poor with a return to just 10dB down at about 15MHz.

I spent about two hours going through everything, including removing the first coil from the board, adding 56pF in parallel with it and putting it in-line between generator output and analyser input. I calculated that it should resonate and provide a notch at 14.47MHz. The analyser showed it to be spot on so my toroidal coil design was correct.

Many times I looked at the board to see whether I had somehow done something silly and connected tracks wrongly or left something unconnected. Eventually I decided that the odd component was the multilayer ceramic 470pF at the input so I changed it for a polystyrene type. The improvement was spectacular, with a notch in the right place to nearly 50dB down but the stopband was not really acceptable, being only 25dB down.

All the other filters were made and tested in turn and I even used a T37-6 for the 10m coils. When all the filters were in place, the characteristics were quite good on some but not all. Then I noticed that when no filter was selected, there were all sorts of returns on the display, suggesting that the input and output lines were suffering crosstalk, probably due to poor earth paths.

When I had laid out the board it had been necessary to link the coils of input and output relays for each filter and this meant a track running almost the full width of the board. The position of this track seriously disrupted the earth path of the shunt capacitors in each filter and increased earth impedance down the board. I linked the earths across from one filter to the next using tinned copper wire and the input to output crosstalk reduced dramatically. When tested by activating each filter in turn, they all had improved to an ultimate attenuation of 35dB or better.

With the filters now operating as required and all with the proper roll-off frequencies, I decided to put it to the RF test and fired up my Yaesu FT-102. I tried the filters on 80m and 40m, putting 50W through them, and everything worked fine with no noticeable heating of coils or capacitors. So I increased the power to 100W and went through all the bands one at a time with key down for a minute or two on each.

On 10m the T37-6 coils did get warm so I rewound both coils using T50-6 cores and then they became only slightly warm to the touch with 100W continuous passing. A picture of the development PCB is shown in **Fig. 2.**

Final Remarks

To overcome the problem of suitable capacitors in the 100pF to 1nF range, I have found some suitable polypropylene capacitors, of a similar size to the boxed polyesters but 4mm (0.15in) wide and with available values 100pF, 220pF, 330pF, 470pF, 680pF and 820pF. I have ordered 100 of each value where I don't have proper NPO disc ceramics.

The PCB artwork has now been modified with the coil connections broken by low value or even zero ohm resistors and with much improved earth tracks linking the filters together. The board has also been extended to include large corner pads for screw fixing, something that was omitted from the original board. As an example of the performance, the screenshots, **Fig. 3**, shows the characteristic of the 80m filter.

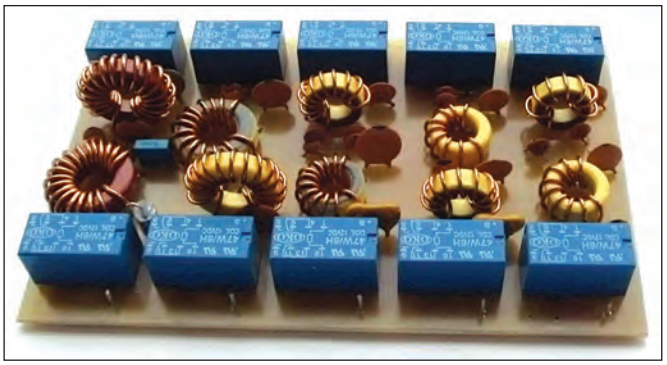

Fig. 2: The development PCB.

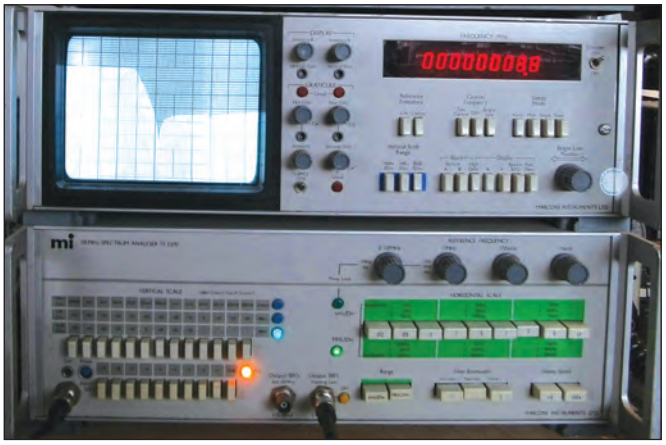

Fig. 3: The 80m filter characteristic as measured in Tony's workshop.

I expect that the modified layout will have even better stopband performance because according to the ARRL table the stopband should be better than 45dB down.

PS – Conclusion of A Modern Crystal Calibrator in last month's Doing it by Design

The photographs below show that a suitable box was found to house the unit and that I had decided to use metal instead of ABS plastic. The reason was that the user can then control the amount of RF coming out of the unit through the BNC socket rather than it radiating from the PCB and wiring. Output levels are 0-1V pk-pk 1kHz, 10kHz, 100kHz and 1MHz and 0-160mV pk-pk at 10MHz.

The original version in the two-part painted aluminium case looked pretty but was a little too large and too expensive. Going for the painted diecast box saves a valuable £5 in boxed version price. Given that some people will have a suitable spare box in the shack, the unit is available boxed or unboxed.

A PCB Kit with 5-way switch and 1kΩ linear level potentiometer will cost £25.25. The same plus a drilled and labelled box and with all the other hardware will cost £57.50. Both prices include tracked carriage by Hermes.